Sorry, wrong number: The use and misuse of numerical "facts" in analysis of energy and environmental issues

Jonathan G. Koomey*, Chris Calwell†, Skip Laitner**, Jane Thornton°, Richard E. Brown*, and Joe Eto*

*Lawrence Berkeley National Laboratory

†Ecos Consulting

**U.S. Environmental Protection Agency

° International Business Machines

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INTRODUCTION

This paper focuses on some key examples of numbers in the energy field that have been widely cited and in several cases have become conventional wisdom, but are either misleading or wrong. It explores where these numbers came from, how they were off the mark, and how they were misused. This review concludes with advice for getting the numbers right for both producers and users of such numbers.

Our overarching goal is to remind readers to be skeptical of anything they read, even from well-established sources. Never base critical decisions on one source of information without corroborating evidence from several others, and use your critical thinking skills to evaluate numerical assertions. For more details on relevant skills and strategies, see Koomey (35).

EXAMPLES

The following examples explore the pedigree of some high profile numbers that have been widely cited. In each case, we try to identify the original source of the number and document its subsequent use in the media and larger analytical community. Such stories are never complete, but they provide insight into just how badly information can be mangled in the retelling, and just how easy it is for incorrect statistics to become conventional wisdom.

HOW MUCH ELECTRICITY IS USED BY OFFICE EQUIPMENT?

Many observers cited statistics during California's energy crisis in 2000 and 2001 indicating that the Internet uses 8% of all U.S. electricity, that all office equipment uses 13%, and that total office equipment electricity use will grow to half of all power use over the next ten to twenty years. These numbers all originated in an article for *Forbes* by Peter Huber and Mark Mills in May 1999 (29). In subsequent research, one of us (Koomey) showed that the Huber and Mills estimate of Internet power use was at least a factor of eight too high (36), and their estimate of total office equipment electricity use was a factor of four too high (31, 32, 37).

What is most intriguing about this story is how the media treated these assertions and their subsequent debunking. We identified six news stories, two magazine editorials, and two investment reports from major banks that cited the erroneous *Forbes* numbers without any indication that there was even a debate about them (this list is illustrative, not comprehensive). Table 1 summarizes those stories.

The errors in the reporting of these numbers are striking for those familiar with the debate. The Energy Information Administration (EIA) has never to my knowledge endorsed the *Forbes* numbers, but EIA has several times been cited as the source. In fact, the former head of EIA, Jay Hakes, publicly disputed the erroneous *Forbes* numbers in Congressional testimony in February of 2000 (25).

The reports from investment banks were particularly troubling, because some investors and media were no doubt influenced by their recommendations, which were based on the flawed numbers. While an exact cause and effect link is often difficult to establish, in one case (that of the editorial in *Energy Markets*) there is a clear link (see quotation in Table 1). Koomey is aware of one major power generation company that was considering altering its strategy in Fall of 1999 based on the assumption of faster demand growth for electricity, although a brief explanation of the measured data soon made them more cautious.

We identified about twenty additional stories that alluded to the debate and reported on it in various ways (2, 5, 6, 9, 19, 22-24, 26, 28, 30, 38, 39, 41, 43-46, 49, 57). Some cited both sides of the debate, giving them equal weight, while others dismissed the Forbes numbers after citing them. The *New York Times Magazine* (24) used the latter approach to characterize the debate: "The West Virginia Coal Association's Web site claims…that computers and the Internet suck up 13 percent of the electricity in America. In fact, the best studies suggest that such activities consume only 3 percent of the nation's electricity." Most articles were less definitive, and simply left the reader with the impression that there was controversy among experts about this topic.

Some reports cited ranges for the percentage of power use associated with computers, often confusing the Internet power use from the total electricity use associated with computers. For example, an Associated Press report (23) stated "It is estimated that the equipment needed to power the Internet consumes from 1 percent to as high as 13 percent of national demand." The 1 percent figure is the LBNL estimate of what Mills' Internet electricity use comes to after correcting for measured data and more accurate assumptions, while the 13 percent is Mills figure for electricity used by all office equipment.

Sometimes one or both ends of the range are from unknown sources, as in an article in the San Jose Mercury News (41): "Depending on who you believe, high technology consumes from 3 percent to 20 percent of the nation's total power generation, and some expect that number to rise to as high as 40 percent by 2010." Where the 20 percent and 40 percent numbers come from is anyone's guess (the 40% may be an average of the 30-50% numbers from the *Forbes* article, but it is not clear). Those presenting ranges (or using qualifying words like "up to 10%") may feel they are being careful. However, they are actually reducing information content with this approach, and readers should be especially cautious when confronted by a range that is not a direct quotation from an expert in the field (and even then, it's best to be cautious in using such numbers without independent verification).

One of the clear patterns after reading all the various articles on this debate is the important role of companies and trade organizations in perpetuating the use of statistics. At least one manufacturer trade group cited the *Forbes* numbers in their press releases, and many reporters simply repeated the press releases verbatim. This lesson is an important one. Many "news" items are actually regurgitated press releases—many news organizations simply reprint press releases without much critical evaluation of their content.

Table 1: Stories that cited the erroneous office equipment electricity use figures without describing the debate

Publication and Date	*Type of publication*	*Quotation*
Deutsche Bank May 2000 (53)	Investment research report	"Mark Mills estimates that by 1999, the growth in (sic) Internet and related IT equipment now consumes 13% of our electricity supplies".
SF Chronicle June 10, 2000 (20)	News article	"Computers and computer peripherals now consume about 13 percent of the nation's available power, a figure that has soared from less than 1 percent since 1993 as the Internet becomes (sic) a preferred method of doing business and communicating."
USA Today June 10, 2000 (3)	News article	"Computers consume about 13% of the nation's power, according to EPRI Corp., a Palo Alto research and development group that studies the utility industry".
Banc of America Securities June 2000 (1)	Investment research report	"Internet-related demand for power represented 8% to 13% of electricity consumption in 1999…It is estimated that by 2010, one-half of U.S. electric consumption will be related to the Internet in some way."
USA Today August 2, 2000 (4)[a]	News article	"The growth is due, in part, to the proliferation of computer and high-tech peripherals…Industry studies found that high-tech paraphernalia had a negligible effect on power usage as late as 1993. Today, it is estimated to account for 13% of all usage. By 2020 it is expected to reach 25%".
Business Week August 14, 2000 (33)	News article	"Fax machines, printers, PCs, and the like already account for up to 10% of commercial electricity use, according to estimates…"
Fortune Magazine August 14, 2000 (48)	News article	Mark Mills "estimates that new-economy sectors—computers, semiconductors, telecom, information storage, and Internet-oriented companies—account for 12% to 14% of the country's power consumption".
Energy Markets August 2000 (47)	Editorial	"Banc of America Securities just launched coverage of the energy industry technology sector. The firm attributes to Huber and Mills the comment, 'Internet-related demand for power represented 8% to 13% of electricity consumption in 1999.'"
Electric Power Research Institute Winter 2000 (18)	Research Institution News Magazine	"Information technology itself now accounts for an estimated 13% of electricity consumption in the United States, and some industry observers believe the IT share may grow to as much as 50% by 2020."
Mechanical Engineering Magazine April 2001 (16)	Editorial	"It has been estimated by the Energy Information Administration that the Internet alone now accounts for nearly 10% of the nation's electricity demand."
ZD Net News May 14, 2001 (34)	News article	"The total energy consumed by the Internet information technology sector…is an estimated 8% to 13% of the nation's electricity, according to data from the Energy Information Administration."

[a]On October 5, 2000 *USA Today* published a correction to their story (55): "In a story August 2, 2000 on a growing shortage of electrical generation capacity, USA TODAY, citing industry figures, reported that computers and their accessories…account for 13% of the nation's power consumption. While there is much debate on the figure, a study by the Department of Energy's Lawrence Berkeley National Laboratory puts that number at about 3% of annual use of electricity."

IS 1 MEGAWATT (MW) EQUAL TO THE ELECTRICITY USE OF 1000 HOMES?

One of the often cited indicators of electricity use is the number of households that can be served by 1 MW of generating capacity. The rule-of-thumb typically used is 1000 households per MW of capacity, implying a load of 1 kW per household. The California independent system operator (CAISO), after discussions with California utilities, began using this equivalence for reporters during the California power crisis, and the California Energy Commission lists it on its official web site,[1] but it is an oversimplification that can lead to confusion. More recently, the CAISO started using 750 households per MW after the California utilities suggested that it was a more representative statistic.

Using the CEC data presented in Brown and Koomey (8), we examine how appropriate this value is for California households. As indicated in Table 2, 1 MW of capacity can serve about 1200 California homes if measured in terms of the electricity produced by that MW in kWh, or about 600 homes at peak times. Table 2 also shows significant variation in these values between utilities.

Table 2: Average Electricity Use per CA Household, 1999

	LADWP	PG&E	SCE	SDG&E	SMUD	Statewide Total
Residential Customers	1,215,000	3,962,000	3,773,000	1,051,000	439,000	11,348,000
Aggregate Residential Consumption (GWh)	7,100	29,000	26,000	6,300	4,000	75,000
Aggregate Residential Peak Load (MW)	1,500	6,900	6,200	1,200	1,400	17,000
Annual consumption (KWh/HH)	5,900	7,400	6,900	6,000	9,000	6,600
Average T&D loss	13%	9.0%	6.5%	6.9%	6.4%	8.1%
Peak T&D loss	11%	9.3%	7.4%	9.3%	9.0%	8.6%
Capacity needed to meet average load (kW/HH)	0.75	0.93	0.83	0.73	1.1	0.82
Capacity needed to meet peak load (kW/HH)	1.3	1.9	1.8	1.3	3.4	1.6

Table taken from Brown and Koomey (8).
Notes: 1) Residential customers are for 1998, as reported in CEC (11).
2) Annual consumption and peak load data are from CEC (52).
3) HH = household.
4) Transmission and distribution losses are from CEC (12), expressed relative to end-use consumption/load.
5) Average load = annual consumption ÷ 8760 hours.
6) Peak load is the statewide residential-sector non-coincident peak load.
7) "Capacity needed to meet load" includes T&D losses but does not consider residential self-generation.

The numbers in Table 2 are averages across all households that mask some important variations. There are different house types that vary greatly in the electricity use and peak demand—a typical single family home might draw three to five kW at peak times, while a typical apartment might be less than 1 kW at peak. Geography and climate are also a large contributor to variation, as shown by the large variation between utility service territories. SMUD is located in California's Central Valley, which is a hot part of the state, and so the peak demand per household is more than 3 kW, compared to the California average of about 1.6 kW. The other four utilities have customer bases that are more concentrated in the coastal areas (where air conditioning is not ubiquitous and the climate is cooler), so their peak demand per household is much lower than that for SMUD.

The consequences of using this simplification are not as critical as those associated with using the incorrect numbers about electricity used by office equipment (in that case, investors and companies were basing their investment decisions on erroneous information). This statistic is a round number that people compared to the size of a new power plant (in MW) or to the shortfall in supply (also in MW) during the power crisis. To our knowledge, few if any decisions are based on the use of this statistic (it is mainly used for publicity purposes), and for that reason, it is a less pernicious number than some of the others explored in this article.

However, it is important for users of this number to understand that it is a simplification that masks a huge amount of variation in household characteristics and geography. It is also susceptible to misunderstanding by people who confuse average and peak loads, although the CAISO always uses it to describe the number of households at peak times.

WHAT IS THE COST OF UNRELIABLE POWER TO THE U.S. ECONOMY?

A key energy policy issue in recent years has been the cost to the U.S. economy of electric power quality problems, such as voltage sags, outages, and transient disturbances (21). One set of aggregate estimates of these costs has been quoted and misquoted over more than ten years, so much so that it is now conventional wisdom, in spite of the crude nature of the original calculation.

One of the first aggregate estimates of the cost of power quality problems to the U.S. economy was made for illustrative purposes in an industry conference paper by Jane Clemmensen. She had been a research engineer at SRI International in the mid-80s and a contractor for the Electric Power Research Institute (EPRI) in the area of power quality, so her estimate of $12.8 Billion per year to $25.6 Billion per year is often attributed to EPRI. The source of these numbers was a technical paper she presented in the opening session of a conference called Power Quality '89 (<www.powersystemsworld.com>). The estimate made clear that the market for solutions, such as uninterruptible power supplies and transient voltage surge suppressors at $1.2B in 1989 was an order of magnitude smaller than the size of the problem industry was experiencing and therefore presented industry with an opportunity to close the gap. The calculation was simple and rough, as befits an illustrative estimate:

> As much as twenty-five cents of every sales dollar in the U.S. manufacturing industries is spent correcting for or accommodating quality control problems of all types, according to quality expert Phillip Crosby. Of this amount, let us

> estimate that 1-1/2 cent to 3 cents is attributable to power quality control. While a true economic study would disaggregate industries and figure the cost to each industry segment separately, taking into account specific data (sales data, energy consumption and demand data, price of electricity), let us simply work with the portion of the gross national product attributable to manufacturing industry sales. In 1987, sales by U.S. manufacturing industries amounted to $853.6 billion in current dollars. The cost of power quality in 1987 by this method is therefore $12.8 to 25.6 billion dollars. (13)

Another formulation in Clemmensen's paper used other independent industry sources to figure the cost to commercial, service sector users at $13.3 billion in 1987. This formulation was probably more defensible, but the number that appeared in newspapers, magazines, vendor product literature, and company business plans was typically the $25B (rounded down), or $26B (rounded up).

The Clemmensen estimate has been widely cited. In 1991, *Business Week* used the top end of the estimate ($26B) in an article (27). In 1992, *The Wall Street Journal* (50) used the bottom end of the estimate ($12B). Neither of these publications quoted the range of the estimate, how it was derived, that it was illustrative in nature, or that it was done in 1989 using 1987 dollars.

In 1993, Clemmensen summarized the original estimate in a sidebar to an IEEE Spectrum article (14) and other analysts have continued to rely on her initial calculation. Swaminathan and Sen (51) cited $26 billion as a measure of the aggregate cost of all reliability problems to the U.S. economy, not just power quality. In addition, the Electric Power Research Institute used Clemmensen's estimate as the basis for a $50 billion estimate of the cost of all reliability problems (1, p. 11), which takes into account the effects of inflation since the time of Clemmensen's original work (17). Brender (7) estimates the U.S. cost of lost productivity due to power quality problems as $15 to $30 billion, but provides no sources or supporting data. Brender's numbers are roughly the same as Clemmensen's, but without clear documentation it is impossible to tell if they were derived from that source.

HOW MUCH ELECTRICITY IS USED BY MISCELLANEOUS APPLIANCES?

Here is another example of how ostensibly official statistics sometimes are created, as recounted by Alan Meier, a long-time friend and colleague at Lawrence Berkeley National Laboratory (LBNL):

> In 1987, Steve Greenberg and I wrote an article in an energy magazine about the rising amount of energy use that did not fit into the traditional categories (42). As part of the article, we created three tables showing ownership of these small appliances (like fish tanks and power tools) and their estimated annual energy consumption. These values were based on very limited monitored data, back-of-the-envelope calculations, and hunches. The tables were assembled in one evening. (Many of the envelopes with calculations were then discarded.)

> In 1989, the U.S. Department of Energy's Energy Information Administration (EIA) published its official *Household Energy Consumption and Expenditures*, including the results of their 1987 survey and additional analysis (54). The EIA published the Meier and Greenberg data in a new table, "U.S. End-Use Consumption of Electricity for Selected Appliances." Whereas we published ranges in our estimates, the EIA just calculated and printed the averages from the high and low values. The word "estimated" appeared nowhere in the EIA table, so the reader was led to believe that these numbers were exact (curiously, the EIA is careful to give confidence bounds and other statistical parameters for its own survey data). To add insult to injury, the EIA misspelled my name in the citation [Koomey, 2001 #2297].

Alan's example is more the rule than the exception. When little information is available about a particular topic, any moderately credible source gets cited by everyone concerned with the topic and becomes the new conventional wisdom. This happens frequently even though such estimates are often based on extremely crude assumptions.[2]. In this instance, one major issue was collapsing ranges into an average, which is another variant of the "floating ranges" problem discussed above.

HOW MANY HALOGEN TORCHIERES ARE THERE IN THE U.S.?

One of us (Calwell) was hired in 1996 to write a research report about the energy and safety problems with halogen torchieres, those inexpensive floor lamps that have become so popular in recent years (10). Here is his story:

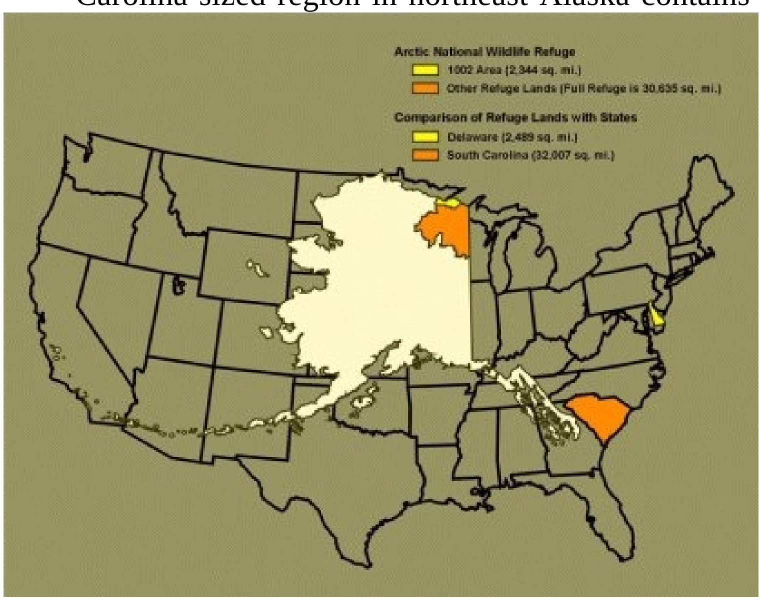
> In order to write the report, I needed to figure out how many halogen torchieres had been sold. The trouble was, nobody knew. The Census Bureau knew how many halogen bulbs had been imported but not how many were in fixtures. California utilities had counted how many were in a small sample of houses, but that was before the lamp had become popular. Market researchers had asked how many people bought halogen lamps of all types but didn't know how many were torchieres. The library was not much help, either, because only two articles had ever been published on this subject before I set out to write mine.
>
> I called the author of those two articles and got the names and numbers of her sources (the manufacturers). Then I called the manufacturers and asked how many they thought had been sold in total the previous year. I also asked them how average prices for the lamps had changed over time and about when they began selling the lamps in the United States. Taking all these different pieces of information under consideration, I created a table of sales of torchieres per year and the number of fixtures still in use at the present time. It was pure guesswork, informed by the information I could find, but guesswork nonetheless, with a fancy spreadsheet and graphs to back it up.
>
> The U.S. Consumer Product Safety Commission, a federal agency, was about to put out a press release on the problems with halogen torchieres at the same time I was finishing my report, but they also had no idea how many had been sold. They

> asked for my number (40 million), which my publisher reported to them as 35 to 40 million to be conservative. The CPSC thought that range seemed high, so it used 30 to 40 million in its press release to be even more conservative. During the next year, dozens of newspaper articles and TV programs cited the CPSC estimate of 30 to 40 million and attributed it to the federal agency, ignoring the original source and never bothering to examine the eight-line footnote in my original report documenting how the original estimate of 40 million was determined (35).

Calwell's estimate had taken on a life of its own through institutional adoption and media repetition. His story is one more example of how numbers of dubious pedigree can reverberate in the media. His experience with "floating ranges" is reminiscent of the treatment of the range of electricity used by computers and office equipment discussed above.

HOW MUCH OIL IS RECOVERABLE FROM THE ARCTIC NATIONAL WILDLIFE REFUGE?

Perhaps the most contentious issues in U.S. energy policy in the last year has been the discussion about drilling for oil in the Arctic National Wildlife Refuge. This South Carolina-sized region in northeast Alaska contains a coastal plain, known as the 1002 area, that is both a key wildlife habitat and a potentially promising area for oil exploration. The 1002 area alone is the size of Delaware, as shown in Figure 1.



The area has been off-limits to drilling since its Refuge designation by President Eisenhower. Limited seismic testing in the 1002 area suggested some potential for substantial oil resources. Subsequent legislation signed by President Carter expanded protections for the area, stating that the 1002 area would require another act of Congress to open for further oil exploration and drilling.

This topic attained a high profile in the media as well, after it became a key point of distinction between the two major presidential candidates and a central feature of President Bush's proposed national energy policy.

The debate has centered largely around the quantity of oil likely to be found in the Refuge. While it is not surprising that proponents of drilling believe large amounts of oil will be found there, and opponents believe the amount is smaller, what is surprising is the extent to which the media has misunderstood and poorly represented the underlying science. With few exceptions, the media has characterized the "story" of the Arctic Refuge as a brawl between impassioned pursuers of economic benefits and equally fervent defenders of wildlife, not bothering to dig into the science itself to understand how much oil is likely to be found. Yet that science holds the key to sound decision-making about the Refuge.

Like other fields of science, the study of petroleum geology employs its own quantitative "language." Though seemingly complex to a layperson, that language revolves around a handful of fundamental precepts of geography, geology, technology, economics, and probability. What follows is a brief background on those issues.

Geography

Most resource estimates to date consider only the amount of oil likely to be found in the 1002 area, while others also include resources in offshore areas controlled by the state and in adjacent native lands. While this increases the total amount of oil likely to be found, it is outside the scope of the present policy debate, which asks the simple question, "Should Congress open the 1002 area to drilling?" As a result, the USGS has concentrated most of its research – particularly regarding economics -- on the federally controlled 1002 area of the Refuge only.

Geology

Petroleum geologists at the USGS began by examining the 1002 area to determine the total amount of *oil in place*. This simply assesses whether the type and age of the rocks in question are conducive to forming and trapping oil. It is akin to estimating the wetness of a vast, unseen, underground sponge. It includes no consideration of how much can be squeezed out of that sponge, by what means, and at what cost.

Technology

Next, the USGS looked in more detail at the physical characteristics of the underground formations where oil is likely to be trapped. Overlaying that resource assessment with an understanding of the current technologies and techniques for extracting oil, they produced estimates of the amount of *technically recoverable oil*. Such assessments include no consideration of economics – they simply estimate the amount of oil we know how to recover by any means at any cost. The USGS published its most recent set of such findings in 1998, after an exhaustive reexamination of all existing seismic testing data for the region.

Economics

Finally, they overlaid technically recoverable estimates with a variety of economic considerations. These include assessments of the likely quality and market value of the particular type of oil found, estimates of the cost of seismic testing and wildcat exploration, and considerations of the specific locations and depths of individual oil fields, to determine drilling and infrastructure costs, minimum economic field sizes (MEFS), and the expected environmental mitigation costs. In addition, they include transportation costs to market and the rate of financial return expected by oil companies from such projects. In short, they constructed an estimate of *economically recoverable oil* using the very same methods a private oil company would use to decide whether to invest its own capital to drill in the hopes of making a profitable oil discovery.[3]

The imprecise treatment of geography and the distinctions between the three basic types of resource assessment – oil in place, technologically recoverable oil, and economically recoverable oil – account for the majority of misunderstanding and misrepresentation by the media regarding the size of the Arctic Refuge resource. But another factor is crucial to understand and include. Both technologically and economically recoverable resource estimates include considerations of probability.

Probability

The USGS builds sophisticated computer models to test a wide range of plausible assumptions for the variables above, and then runs thousands of simulations to determine the range of resulting resource forecasts. Plotting these results on a graph gives something resembling a bell curve: a small number of the estimates predict very low finds and a small number predict very high finds. Most of the estimates cluster in between, allowing the USGS to predict the *mean, 50 percent, 5 percent, and 95 percent* probabilities of finding a particular amount of oil.

Probability and the size of the resource move inversely with each other. So, for example, both the mean and 50 percent forecasts are considered middle-of-the-road, reasonable scenarios, and are usually fairly close in magnitude. The 95 percent forecast is often a very small amount of oil, yet it comes with the virtual certainty of being found. The 5 percent forecast will often point to an enormous amount of oil, yet the likelihood of finding that much is quite remote.

Probability comes into play in another way too. Economically recoverable resource estimates can either be *conditional* or *fully risked*. *Conditional* estimates are appropriate for thoroughly explored regions with well-understood geology. They assume a 100% probability of finding economically valuable quantities of oil, and simply assess how much of it is there.

Fully risked estimates are more appropriate to remote areas like the Arctic Refuge, where much of the detail about underground structures is still unknown.[4] They examine a range of scenarios for the future world oil price, in real dollars, to determine the minimum size a particular oil field needs to be in order to be profitable. These uncertainties are included with others about the region's geology to determine the number of such fields found in the region under study, the amount of oil in each. This ultimately determines the likelihood of a particular amount of oil being economically recoverable.

What the Studies Have Found

As shown in Figure 2, the various studies that have assessed Arctic Refuge oil over the last few decades have predicted widely different amounts of oil.[5] Even studies of the same basic type (i.e., oil in place) have varied substantially, particularly when conducted by some party other than the USGS. Across multiple presidential administrations, the USGS has taken great pains to remain officially neutral regarding the question of whether the Arctic Refuge *should* be opened to drilling, concentrating instead on trying to provide accurate science about the region.

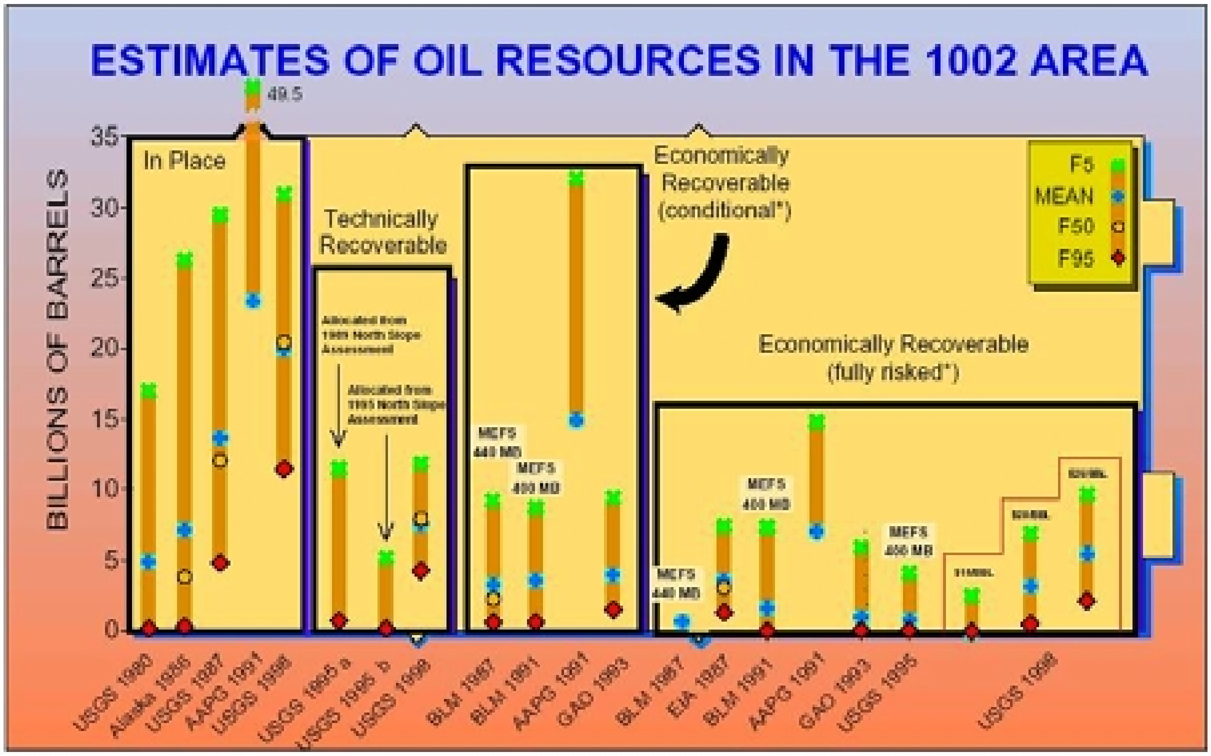


Figure AO21. Comparison of previous estimates of Arctic Refuge 1002 area oil resources with estimates from the current assessment. See text for description of previous assessments and Table AO4 for numbers. USGS 1998 economically recoverable estimates were taken from Figure AO20. MEFS, minimum economic field size. MB, millions of barrels.
* See text for explanation of 'conditional' and 'fully risked'.

Figure 2: Different estimates of the oil reserves in ANWR over time

The most recent and comprehensive USGS studies of the region were published in 1998. The agency reexamined all available geological data (published and proprietary) for the region and nearby wells. It added greater resolution to its economic assessments as well, with scenarios keyed to three market oil price forecasts: \$15, \$20, and \$25 dollars/barrel (1996 dollars).[6] Table ? shows the resulting estimates, in billions of barrels:

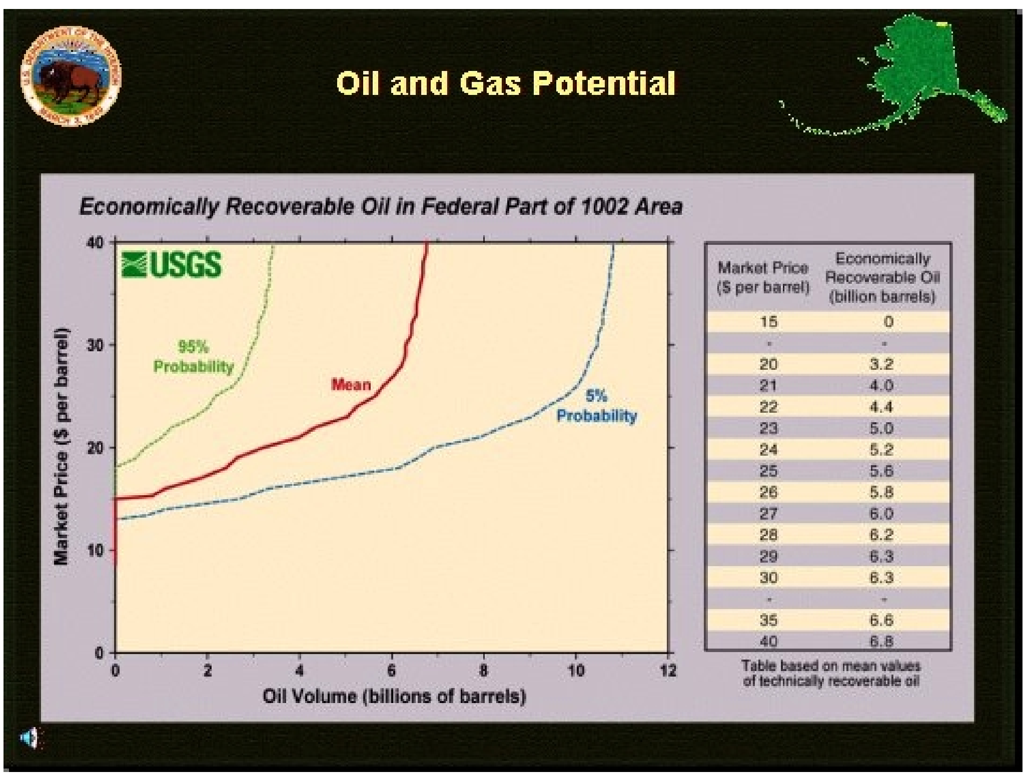
Table 2: USGS estimates of oil reserves in ANWR

Probability	Oil in Place	Technically Recoverable	Economically Recoverable		
			$25/bbl	$20/bbl	$15/bbl
F5	31.5	11.8	9.5	7.0	2.7
Mean	20.7	7.7	5.6	3.2	0
F95	11.6	4.3	2.3	0.7	0

The technically recoverable estimates are about 35 percent larger when the offshore state waters and adjacent native lands are included in the totals. They are 16.0 billion barrels at F5, 10.4 billion barrels at the mean, and 5.7 billion barrels at F95.[7]

The economic studies yield a series of supply curves (one for each probability). All three share the same basic shape (Figure 3).[8] Initially, small increases in price greatly expand the amount of oil likely to be economically recoverable. Eventually each curve reaches a "knee" and then becomes nearly vertical, suggesting that even large additional price increases only minimally affect the resource total.

Figure 3: Economically recoverable oil potential in ANWR



Market Price ($ per barrel)	Economically Recoverable Oil (billion barrels)
15	0
-	-
20	3.2
21	4.0
22	4.4
23	5.0
24	5.2
25	5.6
26	5.8
27	6.0
28	6.2
29	6.3
30	6.3
-	-
35	6.6
40	6.8

The Debate

What has been most intriguing about the debate over the Arctic Refuge is that virtually all stakeholders are arguing from an identical set of numbers from the same source – the 1998 USGS study. Very few advocates have claimed that the research process or science conducted by the USGS is flawed, and that some other study is more accurate. So instead, advocates have simply gravitated toward the *particular* set of numbers that most strongly support their views, and then represented those numbers to the media as USGS findings.

So, from the tables above, proponents of drilling have a number of options for reporting a high estimate and attributing it to USGS. They can select the most favorable geography (whole region, not just 1002 area), a favorable study type (technically recoverable instead of economically recoverable[9]), and a favorable probability (5 percent) to conclude that 16 billion barrels are available for the taking. Or, they can look just at the 1002 area, but move all the way up to oil-in-place studies to state that 20 to 30 billion barrels are there (mean to 5 percent probability). Drilling advocates also commonly quote estimates in the 10 to 12 billion barrel range, which can be found in the mean technically recoverable estimate for the whole region or the 5 percent technically recoverable estimate for the 1002 area.

Opponents of drilling, likewise, could argue that no oil is likely to be found in the Refuge, based on the USGS conclusion that 0 barrels are economically recoverable from the 1002 area at a world oil price of $15/barrel in the mean and 5 percent probability scenarios. Perhaps the most commonly quoted number by opponents of drilling, though, has been the mean estimate of economically recoverable resources at the middle price ($20/barrel) for the 1002 area – 3.2 billion barrels.

News Coverage

The media's response, as noted earlier, has been peculiar. Rather than going back to the original USGS research and publications, they have largely taken at face value advocates' assertions about what the USGS said. So most of the stories follow a rather formulaic pattern – quoting wildly different resource estimates from advocates on both sides and leaving the reader with the impression that the truth is somewhere in between. This is muddled science at best and, on the whole, a great disservice to policymaking.

Using online searching tools, we were able to locate 38 different news stories[10] printed in the last year regarding the amount of oil likely to be found in the Arctic Refuge. Five of the stories included specific references to multiple types of studies, so those are plotted separately, giving a total of 43 specific sets of resource estimates. As shown in Figure 4, those estimates are, literally, all over the map. (Figure 4 is at the end of this document).

Only one story noted the possibility of 0 barrels being recovered, and only one indicated that 20 billion barrels may be found. The most frequently cited estimate was 16 billion barrels, which appeared in 24 of the stories. Other commonly cited numbers were approximately 3 to 3.5 billion barrels, approximately 6 billion, and roughly 10 billion. The average high estimate cited was 13 billion barrels and the average low estimate was 7.6 billion barrels, leaving readers to conclude that a number somewhere in the middle – more than 10 billion barrels – would be "roughly right."[11]

Perhaps most interesting was the absence of clear descriptions for the types of studies being cited. Only 10 of the 43 estimates mention anything about economics in determining how much oil can be recovered, and only 4 of those specifically mention an oil price (one of which misquoted the USGS data by concluding that there is a 95 percent chance of finding 3.2 billion barrels at $20/barrel). None of the stories noted that the price estimates used by USGS were computed in 1996 dollars, meaning that current and future oil prices would need to be discounted by growing percentages for parity with them.

Only 6 of the stories mentioned that the amounts quoted were "recoverable" or "technically recoverable" or "recoverable with current technology" to distinguish them from oil-in-place or economically recoverable estimates. One story noted that is was referring to the total amount of oil in place. So fully 60 percent of the estimates given included no information about the type of study being cited!

Only 2 of the 43 estimates specifically noted which geographic area they were referring to (Refuge + coastal waters and adjacent native lands), leaving highly vague the geographic distinction between the 1002 area and the broader region. Similarly, only 4 of the stories made any distinctions of probability between 5 percent, mean, and 95 percent estimates.

Though 23 stories specifically referred to the USGS as the ultimate source of the numbers, and another 3 referenced the government or "government geologists," few if any of the stories actually quoted someone from the USGS itself. A handful of other stories were content to source estimates to "pro-drilling lawmakers," "oil lobbyists," "experts," and "skeptics."

Conclusions

Given that the Arctic Refuge contains highly uncertain geology, world oil prices fluctuate wildly, exploration and extraction would take 40 to 50 years to complete, and private oil companies will demand a fair rate of return for investing their capital to explore and drill there, the nation must weigh the costs and benefits of drilling there with pursuing other energy policies. So mean, fully risked, economically recoverable estimates become the most meaningful measure of the region's oil potential, leaving the debate largely over the long-term market price of oil.

Considering the range of prices from $15 to $25 a barrel (1996 dollars) yields a range of estimates from 0 to 5.6 billion barrels. However, this range was only reflected by a handful of the news stories covering the topic in the last year.

As the U.S. weighs multiple options for meeting its energy and mobility needs, it is vital that we have accurate information about different policy options. How much would it cost to find 3, 4 or 5.6 billion barrels of oil in the Arctic Refuge? How much would it cost to save that much oil through improved fuel efficiency or alternative fuel sources in vehicles? Over what time period would each resource become available? How does the split between public and private costs and benefits compare in each case?

The answers to those questions form the core of a meaningful debate over the Refuge and, we hope, the basis for more comprehensive and accurate media coverage of that debate. Only then can a fully informed public, in turn, expresses its preferences in polls, in private discourse, and at the ballot box.

LESSONS

Getting the numbers right really matters. If you use the wrong numbers, you will often make the wrong decisions. More than anything else, these examples point to the importance of researchers, business people, and journalists developing critical thinking skills (35). Such skills are almost never explicitly taught, but are essential for anyone trying to make sense of quantitative claims and counter claims in the information age.

GO BACK TO THE ORIGINAL SOURCE

Numbers often become disembodied (separated from the original source). If a number is important to a decision you need to make, find the source and read the documentation. If the documentation is not adequate, then treat the results with skepticism.

Any time you rely on survey data to make an important decision, refer back to the actual questionnaire upon which the survey data are based; otherwise, you risk misinterpreting the data. Read the questionnaire. Find out who asked the survey questions and how they settled on the survey sample. Also determine when the questions were asked, because that can sometimes affect people's responses. Crossen, in her book *Tainted Truth*, recounts a classic example from the early 1990s:

> Consider this question posed by Ross Perot. In a mail-in questionnaire published in *TV Guide*, the question was "Should the President have the Line Item Veto to eliminate waste?" 97% said yes. The same question was later asked of a sample that was scientifically [randomly] selected rather than self-selected, and 71% said yes. The question was rewritten in a more neutral way—"Should the President have the Line Item Veto or not?"–and asked of a scientifically selected sample. This time only 57% said yes (15, p. 112).

To truly understand the meaning of a survey, it is essential to go back to the original survey questions. ***Never*** base critical decisions on someone else's summary of survey results unless you have implicit trust in that person's judgment and understanding of the situation. It is also crucial to understand how the sample of respondents was selected (self-selected samples are the bane of a good analyst's existence). The sample must be truly *representative* of the population or else the results are suspect.

Real data always reflect the inherent inability of humans to track the changes happening all around us. That's why it's important to check data in original sources with intuition, experience, and independent sources of confirmation before taking action.

DON'T BELIEVE EVERYTHING YOU READ

Even respected institutions can spout nonsense. Maintain a healthy skepticism, even of well-established sources. In this age of instant information transmission, rumor and error seem to propagate even more quickly than truth.

Never act solely on information you read in the newspaper or hear over the Internet. News stories are often wrong either because the reporter misunderstood her sources or because the sources themselves were misleading or incorrect. Reporters sometimes report fiction as fact. Email claiming to contain valuable information can easily be a hoax.

One example is that of Stephen Glass, who wrote about 40 articles for the New Republic in the mid-1990s. Almost three-quarters of those stories were “partly or totally bogus,” and the editor of the New Republic was forced in mid-1998 to print a contrite mea culpa when Glass's deceptions were discovered.[12] The standard fact-checking process was not equipped to detect deliberate deception.

GUESSES CAN BECOME “FACTS”

Rough numbers often are elevated to conventional wisdom when there are no other numbers upon which to draw, and incorrect numbers are sometimes repeated enough that they become conventional wisdom. Your best defense against such sanctified guesses is to read the documentation for any data, including the footnotes. Track down cited sources and read them, too. You should be able to figure out the methods used to create any data. If the documentation is not up to this task, you should regard the data with extreme suspicion. Don't ever use data unless you know how they were derived, you trust the cited sources, and you agree with the stated methods (35).

EVEN REAL DATA ARE UNCERTAIN

Lutter (40) gives the example of various estimates of 1990 U.S. carbon emissions over time. He found that EIA revised these estimates nine times between 1992 and July 2000, and that the estimates varied by as much as 1.2% from the 1992 estimates at different times. This difference is not a large one, but it is striking that such a basic statistic as carbon emissions in a historical year is not known with certainty. The purpose of this example is not to criticize EIA's revisions (which are laudable and necessary as better data become available) but to illustrate that uncertainty is pervasive, even in what should be relatively well known quantities.

DIG INTO THE NUMBERS

Dig into the numbers, and compare results to other numbers you know to be true (35). Are results consistent with other sources? Can you find internal inconsistencies that cast doubt on the results?

Anyone who has delved into data from the real world knows that they're messy. Survey takers can write down the wrong response. People entering data from a survey form into a computer can type in the wrong numbers. Computers sometimes garble data because of software bugs (especially when converting one file format to another). Data formats become obsolete as software changes. Electronic data recorders break or go out of adjustment. Analysts mislabel units and make calculational errors.

It is crucial to pore over raw survey data to check for anomalies before doing extensive analyses. For example, typographical errors can lead numbers to be ten, or a hundred, or a million times bigger than they should be. Looking over the raw data can help you identify such problems before you waste time doing statistical analysis using incorrect numbers.

Bad data ruin your credibility and call your work into question. Even if there’s only one small mistake, it makes your readers or listeners wonder how many other mistakes have crept into your analysis. It’s difficult to restore your credibility after some obvious mistake is revealed, so avoid this problem in the first place. Dig into your numbers and root out these problems *before* you finalize your paper or talk.

Check that the main totals are the sum of the subtotals. Most documents are rife with typographical errors and incorrect calculations. You should therefore not rely blindly on any data source's summations but calculate them from the base data. You can check your typing accuracy by comparing the sums to those in the source of data. If they match exactly, it is unlikely that your typing is in error. Even if you don’t check these sums, you can bet that some of your readers or listeners will. Do it yourself, and avoid that potential embarrassment.

Check that the input data are current. Don’t forget that official statistics get revised all the time. Make sure you know the vintage of the input data used in the analysis. For example, don’t compare analysis results generated using one year’s Census data with those based on another year’s data (unless your sole purpose is to analyze trends over time).

Check relationships between numbers that should be related in a predictable way. Such comparisons can teach valuable lessons. For example, when examining data on carbon emissions of different countries, a newcomer to the field of greenhouse gas emissions analysis might expect that the amount of carbon emitted per person would not differ much among industrialized countries. In examining such data, however, we find large differences in carbon emitted per person, from less than 1 metric ton/person/yr in Portugal to more than 6 tons/person/yr in Luxembourg. Determining why such differences exist is the logical next step, which will inexorably lead to further analysis and understanding.

Check that you can trace someone else's calculation in a logical way. If you can't, you can at least begin to list the questions you need to answer to start tracing the calculation. Ultimately, if you can't reproduce the calculation, the author has broken a fundamental rule of good data presentation, and his analysis is suspect.

Compare the numbers to something else with which you are familiar, as a "first-order" sanity check. These comparisons can show you whether or not you are on the right track. Presenting such comparisons in reports and talks can also increase your credibility with your readers or listeners because it shows that your results "pass the laugh test."

Normalize numbers to make comparisons easier. For example, the true size of total U.S. Gross National Product (GNP) in trillion dollars per year is difficult to grasp for most people but if normalized to dollars per person per year will be a bit more understandable. Common bases for such normalizations are population (per person/per capita), economic activity (per dollar of GNP), or physical units of production (per kilowatt hour or per kilogram of steel produced).

When John Holdren was a professor at UC Berkeley, he taught a delightful class titled Tricks of the Trade. In this class he described many of the unwritten rules about being effective in the energy/environment field and listed key pitfalls in data acquisition and handling. I aggregate them below into four golden rules:

- *Avoid data that are mislabeled, ambiguous, badly documented, or otherwise of unclear pedigree*. Ambiguity and poor documentation are an indication that the quality control for such data is uneven at best and appalling at worst. Dig into the numbers a bit and find out whether it's carelessness or incompetence; make sure you believe the numbers before using them.

- *Discard unreliable data that are invented, cooked, or incompetently created*. If you find major inconsistencies, conceptual flaws, and omissions in the data, you'll need to discard them, no matter how much they might help your analysis.

- *Beware of illusory precision.* Don't represent or interpret data as more accurate than they are. Carefully characterize uncertainty and variability in your data, and insist that others do so with their own.

- *Avoid spurious comparability*. Beware of numbers that are ostensibly comparable but are fundamentally inconsistent. Create and use only consistent comparisons.

Holdren's advice when dealing with data is to "be suspicious, skeptical, and cynical. Assume nothing." Though it may sound paranoid to the uninitiated, such caution is an absolute necessity for the seasoned analyst.

USE "BACK OF THE ENVELOPE" CALCULATIONS

When confronted by the numerical assertions of others, check them in a rough way using "back of the envelope" calculations, just to be sure. The physicist Enrico Fermi used to dole out exam problems but not supply all the information necessary for a solution. His students were expected to make educated guesses about the missing parameters to solve these so-called "Fermi problems." This technique is not often taught in school, but it is one that should be widely used, not just by scientists, but by people in many walks of life.

For virtually any problem, it is possible to create an approximate solution using information you know or can estimate from daily life experience. Most people don't believe this until they try it a few times, but it's true. For examples and advice about creating such calculations, see Koomey (35).

Hans Christian von Baeyer (56) points out that doing such calculations instead of relying on authority engenders self-confidence and independence. Achieving even occasional success in back-of-the-envelope estimation increases your inclination to tackle such problems in the future, thereby ensuring that you will gain further experience and self-assurance. To know in your heart that you can roughly estimate just about anything is a marvelous feeling of mastery.

ADVICE FOR JOURNALISTS

When quoting numbers of any kind, there are some key pitfalls to avoid:

1) avoid giving ranges that reduce the data content of the numbers being reported. Don't combine incomparable numbers in ranges, and don't extend ranges to be "conservative". If a source cites a range, make sure you understand exactly what that range represents, and report it as they said it.

2) Don't assume that all debates have two equal sides. In some fields (particularly scientific fields), there ARE right and wrong answers, and by highlighting a few skeptics instead of presenting the balance of scientific opinion, you do the public debate a disservice.

3) Watch out for inflation when quoting dollar figures. In the estimates of power quality costs to the U.S. economy, this mistake has been one of the most common. The value of money is affected by inflation, and over time, inflation makes each dollar worth less, so a dollar spent in 1997 is *not* the same as a dollar spent in 1990. You must therefore report the year in which expenditures occur and only compare numbers that have been corrected for inflation in a certain year (for details on how to do these simple calculations, see (35, p. 156)).

CONCLUSIONS

Misuse of numbers is all too common, but use of relatively simple techniques can help you avoid the most common pitfalls. This paper explored several prominent examples from the energy field where rough or wrong calculations were adopted by institutions and became conventional wisdom through media repetition. Energy and environmental analysts should heed the lessons from the examples above when talking with the media, and recognize the ways that their numbers may be used or misused when crafting their words.

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[1] For example, see the definition of MW at <http://www.consumerenergycenter.org/glossary/m.html>.

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[2] No matter how rough they may be, Alan's estimates are based on years of experience and professional judgment. They prompt further empirical work that more often than not supports his initial guesses.

[3] See, for example, "Oil Cos. Say Pipeline Too Pricey," Associated Press, September 27, 2001 (http://news.excite.com/news/apl/010927/16/gas-pipeline), noting that Exxon Mobil, BP, and Phillips Petroleum found that a natural gas pipeline from the North Slope of Alaska to the Lower 48 would be too risky and uneconomic, because it would likely only provide a 10 to 11 percent return on investment, instead of the 15 percent desired. The USGS assumed a 12 percent rate of return in its Arctic Refuge analysis.

[4] Personal communication, Kenneth Bird, lead Arctic Refuge geologist, USGS, February 2001.

[5]This is a reprint of Figure AO21 from the USGS CD-ROM, *The Oil and Gas Resource Potential of the Arctic National Wildlife Refuge 1002 Area, Alaska,* Open File Report 98-34, 1998.

[6] The distinction between "market price" and "world oil price" is a significant one. Given the difference in quality between Alaskan North Slope crude oil and West Texas Intermediate crude, which serves as the benchmark for world oil prices, "market price is actually a few dollars below world oil price in this case, and must also include the cost of transporting the oil from the Refuge to refineries and markets in the Lower 48.

[7] USGS CD-ROM, Table AO3, *The Oil and Gas Resource Potential of the Arctic National Wildlife Refuge 1002 Area, Alaska*, Open File Report 98-34, 1998.

[8] See http://www.doi.gov/arctic/ for federal briefing on the Arctic Refuge, in which this figure appears.

[9] Their distinctly optimistic rationale is that technology will continue to march along in the coming decades, virtually insuring that whatever it technically recoverable now will be economically recoverable by the time we actually drill in the Refuge.

[10] This list includes all stories I was able to find that were published in the last year and did not appear in advocacy or trade association publications. All were written by journalists; editorials and opinion pieces were specifically excluded from consideration.

[11] If only one estimate was provided, it was treated as both the high and the low for that particular story.

[12] You can read the *New Republic's* letter of apology at <http://magazines.enews.com/magazines/tnr/current/ourreaders060198.html>.

The Amount of Oil in the Arctic Refuge, as Characterized in Recent News Stories